

Optimizing Logistics Distribution in Archipelagic Economies: A Case Study of North Sulawesi

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ABSTRACT: This study aims to examine the determinants of logistics distribution efficiency in North Sulawesi, Indonesia, an archipelagic region with unique geographical challenges. Using a quantitative explanatory design, data were collected through structured questionnaires from 55 purposively selected logistics stakeholders, and analyzed using multiple linear regression with validity and reliability testing. The results show that delivery time has the strongest positive influence on distribution efficiency ($\beta = 0.482$; $p = 0.001$), followed by infrastructure and technology ($\beta = 0.317$; $p = 0.021$), while distribution cost negatively affects efficiency ($\beta = -0.215$; $p = 0.034$). These findings highlight the critical role of timeliness and technological adoption in overcoming logistical barriers in archipelagic settings. The study contributes by offering practical recommendations for multimodal transport integration, digital adoption, and infrastructure investment to strengthen logistics performance in geographically dispersed economies.

Keywords: Logistics Efficiency, Delivery Time, Infrastructure And Technology, Distribution Cost, Archipelagic Economy



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INTRODUCTION

Logistics distribution serves as a foundational component in supply chain systems, directly influencing cost efficiency, delivery timeliness, and broader economic performance. This interrelationship becomes particularly significant in geographically complex and fragmented regions such as North Sulawesi, Indonesia. As an archipelagic province, North Sulawesi possesses both strategic economic potential and inherent logistical challenges due to its terrain and dispersed landforms. The province comprises not only mainland areas but also small and isolated islands like Sangihe and Talaud, which complicate the distribution of goods across the region. These conditions necessitate a specialized understanding and approach to enhancing logistics efficiency within such contexts.

Distribution inefficiencies have become a critical bottleneck for regional development, with transportation infrastructure across North Sulawesi still uneven. Roads in rural and remote areas remain underdeveloped, and maritime transport services are limited or irregular. These logistical constraints result in high distribution costs, slow delivery times, and ultimately, hinder local economic activity. For instance, the distribution cost of the subsidized rice (raskin) program in North Sulawesi reached over IDR 5.28 billion in 2016, revealing the urgent need for optimized logistics systems. The LPG 3 kg distribution across the province had only achieved 48.8% of its target by May 2025, demonstrating the persistent inefficiencies in inter island delivery routes. Additionally, the horticultural sector in Minahasa Selatan, which produced 114,115 tons of vegetables in 2011, highlights the growing demand for efficient transportation of perishable goods from rural production hubs like Modoinding to urban markets in Manado.

These local challenges reflect a broader national issue: Indonesia's logistics costs amount to 21.23% of its GDP, markedly higher than other ASEAN nations. The elevated costs and infrastructural inefficiencies present a significant barrier to competitiveness, both locally and internationally. Hence, the need to improve logistics performance in North Sulawesi is not just a matter of operational efficiency but also of economic necessity. Disparities in pricing between regions, accessibility to markets, and customer satisfaction are all influenced by the capacity of logistics systems to deliver timely and cost effective services (1).

Previous studies in logistical management have affirmed the critical role that distribution efficiency plays in regional economic growth. Logistics inefficiencies restrict trade, raise operational costs, and compromise a region's global competitiveness. Charlampowicz and Mankowski (2024) argue that improved logistics performance can lead to lower costs and better market access, directly impacting economic prosperity. Moreover, logistics enhancements can catalyze investment, encourage innovation, and support the broader development agenda in developing economies (2,3).

A comparative look at ASEAN countries positions Indonesia as a high cost logistics country, mainly due to underdeveloped infrastructure, complex regulatory frameworks, and limited adoption of digital technologies in supply chain operations (4). This situation hinders domestic enterprises from achieving the level of efficiency seen in neighboring countries such as Thailand, Vietnam, and Malaysia, where logistics reform and digitalization have led to significant improvements. By understanding these disparities, policymakers can formulate targeted interventions to enhance infrastructure and digital capabilities in lagging regions like North Sulawesi.

Infrastructure is universally acknowledged as a cornerstone of effective logistics performance. In North Sulawesi, the absence of adequate transportation networks has impeded logistical advancement. Poor road conditions, limited port connectivity, and unreliable inter island shipping schedules create delays and increase costs. Gossler et al. (2019) note that last mile delivery in such areas becomes particularly problematic, impeding the reliable flow of goods (5). Additionally, environmental challenges, such as rough seas and seasonal weather disruptions, further complicate transportation logistics. Investment in port facilities, road improvements, and transportation fleet modernization are therefore crucial steps toward resolving these issues (6).

Digital infrastructure has emerged as an equally critical dimension of logistics performance. The rise of e commerce, coupled with increasing consumer expectations for fast delivery, underscores the need for digitalized logistics solutions. Real time tracking systems, digital route planning, and warehouse automation are no longer luxuries but necessities. Thunberg and Fredriksson (2022) emphasize that digital tools enhance visibility, responsiveness, and control in logistics processes. However, many small and medium sized enterprises (SMEs) in North Sulawesi continue to rely on manual methods, lacking both the resources and capacity to adopt modern logistics technologies (7). Furthermore, unreliable internet access in remote areas restricts the effectiveness of such tools, perpetuating existing inefficiencies (8).

In regions like North Sulawesi, logistical challenges are amplified by geographical complexity, making a systemic approach to logistics reform essential. Several studies advocate for an integrated model that incorporates cost structures, time sensitivity, and technological capability. Rudberg and Maxwell (2019) highlight that the interplay of these variables significantly shapes logistics efficiency, while Assis et al. (2023) provide quantitative evidence that investments in technology can trigger cascading improvements across other dimensions, including cost reduction and enhanced timeliness (9)(10). This interconnectedness emphasizes the importance of multi-variable analysis to inform logistics strategy.

This study employs a quantitative explanatory design to test the statistical relationships among these variables. By doing so, it seeks to provide data-driven recommendations for policymakers and logistics practitioners to reduce costs, accelerate delivery times, and strengthen technological readiness.

While distribution cost has traditionally been viewed as the central factor of efficiency, this research compares its influence with other determinants, namely delivery time and digital infrastructure. The expectation is that faster delivery and improved technology adoption can offset inefficiencies caused by high costs, resulting in overall performance gains. More specifically, delivery time is hypothesized to have the strongest impact on logistics efficiency, consistent with earlier findings on regional supply chain competitiveness.

The current body of literature on logistics in developing nations often focuses on single variables or case-specific analyses. This study differentiates itself by integrating multiple factors into a unified analytical framework and applying it to the archipelagic context of North Sulawesi. By including empirical data from SMEs, logistics managers, and distribution agents, the research strengthens both relevance and practical applicability. In this way, it addresses a notable research gap, since most existing models have been developed in continental or urban settings rather than dispersed island regions.

METHOD

Research Design

This study adopts a quantitative research approach using an explanatory design to examine the causal relationships between the independent variables distribution cost (X1), delivery time (X2), and infrastructure and technology (X3) and the dependent variable, distribution efficiency (Y). The explanatory nature of the design allows the researcher to validate hypotheses about the influences of logistical factors using empirical data collected through field research. This approach enables a structured, data driven analysis to understand how each factor contributes to overall logistical efficiency in North Sulawesi.

Research Location and Population

The study is geographically situated in North Sulawesi Province, Indonesia. The key observation areas include Manado, Bitung, Minahasa, and the Sangihe Islands, selected due to their high distribution activity and geographic representation of mainland and island logistics. The population of the study consists of logistics stakeholders such as goods distributors, warehouse operators, SME owners involved in logistics, and logistics managers. Their involvement provides comprehensive insight into the logistical dynamics across varied terrain and infrastructure conditions.

Sampling Technique

This study employs purposive sampling, selecting respondents who possess specific expertise and operational experience in the logistics and distribution sector. To ensure the quality of data, inclusion criteria were defined: respondents must have at least two years of experience in logistics, actively operate in North Sulawesi, and be willing to complete the survey responsibly. A total of 55 respondents were selected, a sample size deemed sufficient for conducting multiple linear regression analysis given the simplicity of the model and the assumption of normally distributed data. Purposive sampling enhances the relevance of insights obtained, as recommended in logistics research best practices.

Data Collection Techniques

The data collection process utilized both primary and secondary sources. Primary data were collected through structured questionnaires using a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). The questionnaire measured four key constructs:

- X1 (Distribution Cost): fuel cost, packaging cost, toll fees, and labor expenses.
- X2 (Delivery Time): average delivery time and frequency of delays.
- X3 (Infrastructure and Technology): access to ports, information systems, and digital route management.
- Y (Distribution Efficiency): timeliness, cost efficiency per delivery, and customer satisfaction.

The questionnaire items were compiled based on established logistics literature and adapted indicators, as detailed in the operational definition table provided in the appendix. Prior to analysis, all items underwent validity testing (Pearson correlation) and reliability testing using Cronbach's Alpha, with coefficients exceeding the recommended threshold of 0.70, indicating internal consistency.

Secondary data were obtained from North Sulawesi's Central Statistics Agency (BPS), Ministry of Industry and Trade, World Bank Logistics Reports, and relevant academic studies, ensuring triangulation and contextual accuracy.

Data collection was conducted between February and April 2025, covering both mainland and island regions. It should be noted that the sample size of 55 respondents, while sufficient for regression analysis, limits the generalizability of findings to broader national policy contexts. Therefore, the results are interpreted as indicative for regional logistics practices in archipelagic areas rather than universally representative.

Data Analysis Techniques

The data were analyzed using multiple linear regression with the aid of SPSS version 26. The analytical procedure comprised several steps:

- **Validity and Reliability Testing:** All questionnaire items underwent statistical testing to ensure their accuracy and consistency.
- **Classical Assumption Tests:** These included normality, multicollinearity, and heteroscedasticity tests to validate the regression model.
- **Model Testing:** The coefficient of determination (R^2), F test, and t test were conducted to evaluate the significance and explanatory power of each independent variable.
- **Interpretation of Regression Coefficients:** Each beta coefficient was interpreted to understand the magnitude and direction of influence that X1, X2, and X3 have on Y.

These techniques are well established in logistics studies for identifying significant predictors of distribution efficiency (11,12).

RESULT AND DISCUSSION

The multiple regression analysis indicates that the overall model is statistically significant, with an F-statistic of 15.72 ($p < 0.001$), confirming the feasibility of the regression model. The model explains 61.3% of the variance in logistics distribution efficiency ($R^2 = 0.613$), suggesting a strong explanatory power.

To provide clarity, the following subsections present the results for each independent variable.

Distribution Cost (X1)

The descriptive analysis shows that distribution cost obtained a mean of 3.21 (SD = 0.65), indicating that most respondents perceive costs as moderately high. Regression results reveal a significant negative influence on efficiency ($\beta = -0.215$, $p = 0.034$). This finding suggests that higher costs reduce the effectiveness of logistics operations, especially across island regions.

Delivery Time (X2)

Delivery time recorded the highest mean of 3.47 (SD = 0.58). Respondents in urban areas such as Manado and Bitung reported greater reliability, while island regions like Sangihe and Talaud experienced more delays. Statistically, delivery time has the strongest positive effect on efficiency ($\beta = 0.482$, $p = 0.001$), underscoring its role as the most critical driver in logistics performance.

Infrastructure and Technology (X3)

The mean score for infrastructure and technology was 3.02 (SD = 0.72), reflecting limited and uneven adoption of digital tools and infrastructure. Despite these challenges, the regression results confirm a significant positive relationship with efficiency ($\beta = 0.317$, $p = 0.021$). This indicates that investments in infrastructure and technology contribute meaningfully to long-term logistics improvements.

Overall Efficiency (Y)

The dependent variable, logistics distribution efficiency, obtained a mean score of 3.38 (SD = 0.60), suggesting a generally satisfactory performance. However, disparities in cost and technology adoption highlight areas requiring systemic reform.

3.5 Regression Analysis of Variable Relationships

The multiple regression analysis shows that the overall model is statistically significant ($F = 15.72$, $p < 0.001$) and explains 61.3% of the variance in logistics distribution efficiency ($R^2 = 0.613$). This indicates a strong explanatory power of the model.

Table 1. Regression Model Summary

Variable	Beta Coefficient (β)	Significance (p-value)	Effect Direction
X1: Distribution Cost	-0.215	0.034	Negative (reduces efficiency)
X2: Delivery Time	0.482	0.001	Positive (strongest influence)
X3: Infrastructure & Technology	0.317	0.021	Positive (moderate effect)
Model Fit	$R^2 = 0.613$	$F = 15.72$, $p < 0.001$	—

Delivery time is the most influential factor in improving logistics efficiency, followed by infrastructure and technology, while distribution cost has a negative impact.

The findings from this study reinforce the complex and multifactorial nature of logistics distribution efficiency in archipelagic regions such as North Sulawesi. Among the three tested independent variables, delivery time emerged as the most influential factor, followed by

infrastructure and technology, and lastly by distribution cost. These results are consistent with previous research, validating the hypothesis that in geographically fragmented economies, logistical success is increasingly determined by timeliness and the level of technological integration.

The significant negative influence of distribution cost on efficiency ($\beta = -0.215$; $p = 0.034$) corroborates observations from prior literature that excessive logistical expenditures hinder the overall effectiveness of distribution networks. High costs, especially in island based supply chains, stem from fuel dependency, labor intensity, and inadequate economies of scale. To mitigate these issues, scholars recommend the adoption of lean logistics practices, cooperative transport schemes, and the deployment of automation to minimize recurring costs (13,14). For regions like North Sulawesi, local partnerships and adaptive logistics strategies tailored to unique geographical realities could offer meaningful cost reductions and enhance sustainability.

In contrast, the strongest positive effect on distribution efficiency was observed for delivery time ($\beta = 0.482$; $p = 0.001$), underscoring its centrality in effective supply chain management. The ability to ensure prompt deliveries across a dispersed geography significantly impacts customer satisfaction and operational reliability. This aligns with studies emphasizing the critical role of transportation speed and predictability in logistics performance (15). Investments in multi modal transportation systems, especially integrating land sea air networks, can reduce bottlenecks and adapt to logistical constraints posed by weather and inter island dependencies. Strategic route planning and fleet optimization, supported by real time tracking, are key interventions for enhancing this dimension.

The infrastructural and technological dimensions ($\beta = 0.317$; $p = 0.021$) showed a moderate yet significant influence on distribution efficiency. Despite being the lowest rated factor by respondents, its statistical impact reveals that infrastructure and technology can serve as levers for long term efficiency gains. Regions with inadequate road and port facilities suffer from slower movement and limited capacity for goods handling, whereas areas lacking digital infrastructure face data inaccessibility, poor visibility, and coordination failures. As highlighted by Nilsson (2019) and Liu et al. (2019), digital transformation via IoT, cloud platforms, and mobile systems facilitates synchronized logistics networks that adapt dynamically to operational disruptions (16,17).

Incorporating these technologies in North Sulawesi's logistics ecosystem would require not only financial investment but also substantial training and capacity building, particularly for SMEs and local distributors. Public private partnerships (PPP) can be instrumental in mobilizing resources for digital infrastructure expansion while ensuring local inclusiveness. Furthermore, digital solutions tailored for rural contexts including offline functionalities and SMS based notifications can bridge the digital divide and enhance participation in formal logistics systems.

Beyond individual factor analysis, the combined regression model affirms that holistic strategies are essential for sustainable logistics performance. The statistically significant contributions of all variables suggest that isolated interventions are unlikely to yield optimal results. Instead, integrated approaches that simultaneously address cost, speed, and infrastructure are required. This echoes conclusions from systems based logistics research which argue that the interplay among structural and operational variables defines distribution efficiency (18).

In light of this, several strategic pathways can be drawn. First, targeted infrastructure development focusing on under connected islands should be prioritized. Enhancing port access, improving inter island ferry schedules, and developing logistics hubs in remote districts can create more equitable and efficient networks. Second, logistics innovation hubs or incubators can be established in urban centers like Manado or Bitung to foster collaborative experimentation with smart logistics technologies. These hubs can serve as training centers, data labs, and innovation accelerators for regional actors.

Third, policy support through tax incentives for logistics firms adopting green or digital practices can catalyze broader transformation. Regulatory frameworks must also be reformed to facilitate faster permits for intermodal logistics, while subsidizing technology adoption among micro logistics providers. The World Bank and regional development agencies can play a crucial role by channeling financial and technical assistance aligned with these objectives.

Lastly, local governments must actively engage with community actors, cooperatives, and private companies to co design logistics systems that reflect regional values and capabilities. Participatory logistics planning that includes rural voices can unearth context specific insights and foster a sense of ownership that enhances compliance and system durability (19,20).

Taken together, the implications of this study extend beyond Sulawesi Utara. They highlight the fundamental need for adaptive, inclusive, and technology driven logistics strategies in developing archipelagic contexts. Further research should explore longitudinal impacts of digital adoption and infrastructure upgrades on delivery precision, cost containment, and environmental sustainability. Such research would help establish a dynamic knowledge base for resilient logistics planning in emerging economies.

CONCLUSION

This study analyzed the effects of distribution cost, delivery time, and infrastructure and technology on logistics distribution efficiency in North Sulawesi. The findings show that all variables significantly influence efficiency, with delivery time as the strongest factor, followed by infrastructure and technology, while distribution cost negatively affects performance. The study's novelty lies in its integrated approach to cost, time, and technology in an archipelagic setting, offering theoretical insight into how timeliness and digital readiness can counterbalance high logistics costs in geographically fragmented economies.

Practically, the results underscore the importance of multimodal transport integration, investment in digital infrastructure, and collaborative strategies between public and private sectors to enhance logistics performance. Future research should involve larger samples, longitudinal analysis, and the inclusion of environmental and social aspects to broaden the understanding of sustainable logistics in archipelagic regions.

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